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Shaft-Sinking Investigation

Johan de Beer

Mining 68
Spring Semester, 1956
Mining Methods

Report
Submitted to
Professor K. S. Stout

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Residence Hall
Montana School of Mines
Butte, Montana
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Professor Koehler S. Stout
Montana School of Mines
Butte, Montana

Dear Professor Stout:

In acordance with your request of September 29, 1955, I herewith submit my report on " Shaft-Sinking Practices ".

The report "Shaft-Sinking Practices" does not cover the specific methods used at different localities in detail, but only the general practices used. In this report I tried to give a general picture on shaft sinking and tried to cover all general phases of sinking. Most of the material for this report was gathered from technical journals in the library.

Respectfully submitted

Johan de Beer

Johan de Beer

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SHAFT-SINKING PRACTICES

INTRODUCTION

During the past few years there has been a tremendous advance in the rate of sinking shafts. The sinking of shafts has always been one of the more costly and time consuming operations in the development of a mine. Shaft sinking is a long-term operation and only in the past few years has there been a remarkable increase in the rate of sinking. Shaft sinking ties up a great amount of capital which cannot be released until the production stage of a mine is reached. As a result of the tied up capital and the time consumed the trend in modern mining practice is to faster and higher efficient sinking operations.

As a result of an increase in the cost of labor and the decrease in skilled labor available, the trend is towards increased mechanization to lower the man-hour consumption. The scarcity of shaft labor has also compelled industry to mechanize as much as is practical, feasible and economical. Mechanization which plays only a part of the entire sinking cycle must be taken into consideration in the other phases of shaft sinking which cannot be mechanized. Mechanism lessens the physical and mental fatigue of the workers.

Other important phases enter into the picture of shaft sinking as stated by Mr. Martin J. Tucker, master sinker for West Rand Consolidated Mines, Ltd., Krugersdorp, Union of South Africa.

After setting a new world record in shaft sinking of 763 ft. in 30 days he stated that the achievement was due to "intensive organization and team work; careful attention to detail, planned storing, and movement of materials on and of the bank, and -- above all -- the unfailing and unflinching cooperation of the crew and mine staff." [1]

With better organization and beforehand planning it is thus possible to increase the efficiency and sinking rate of shafts.

To form an idea on the advancement made during recent years in shaft sinking we will compare the world's sinking records for round and rectangular shafts in one month's time over a period of ten years, as listed in Table No. 1. From the tables we see that over a period of four years there has been an increase of 259 ft. per month. It is also of interest to note that the world's record in shaft sinking for one month's time, of 763 ft. was established by hand mucking. This fact seems to point out that mechanical mucking is still far from efficient as could be wished for. Another point of interest is the increase of circular shafts over rectangular shafts.

The question that now arises is; "how was this increase in the sink-rate of shafts brought about?" In the next few pages the problem of increasing the sinking rate will be discussed.

SHAFT PLANNING

Many a problem faces the mining engineer in the design of a shaft. The mining engineer must have a thorough knowledge

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1 ,......., Mining World, December, 1955,vol. 17,no. 13;p. 64.

World's Sinking Records For Round and Rectangular Shafts In One Month's Time

Mining Company and Shaft	*Location*	*Feet Sunk*	*Month, Year*	*Type*	*Size*	*Formation Penetrated*	*Lining*
West Rand Consolidated Mines, Ltd. Monarch	Krugersdrop, Transvaal, South Africa	763[1]	September 1955 (30 Days)	Rectangular	20 by 12 feet excavated	Witwatersrand Quartzite, Kimberley shale	Timber sets
Vaal Reefs Exploration and Mining Co., Ltd. No. 1 Ventilation	Klerksdrop, Transvaal, South Africa	667	March 1955 (31 Days)	Circular	20-foot-diameter, excavated. 18-foot lined	Quartzite and shale	Concrete
Merriespruit Orange Free State Gold Mining Co., Ltd. No. 2	Virginia, Orange Free State, South Africa	597[2]	June 1954 (30 Days)	Circular	Four compartments, 26.5 feet excavated 24.5 feet lined	Quartzite and shale	Concrete
Vlakfontein Gold Mining Co., Ltd. No. 2	Heidelberg, Transvaal, South Africa	585[2]	May 1953 (31 Days)	Circular	for downcast ventilation, 26.5 feet excavated 24.5 feet lined	Quartzite and shale	Concrete
Hartebeestfontein Gold Mining Co., Ltd. No. 2	Klerksdrop, Transvaal, South Africa	518[1]	May 1954 (31 Days)	Circular	Four compartments, 23.0 feet excavated 21.0 feet lined	Quartzite and shale	Concrete
Virginia Orange Free State Gold Mining Co., Ltd. No. 3 Shaft.	Virginia, Orange Free State, South Africa	504.0	April 1951 (30 Days)[3]	Circular	24-foot diameter 26.5-foot excavated	Karroo shales	Quick setting concrete
Virginia Orange Free State Gold Mining Co., Ltd. No. 3 Shaft.	Virginia, Orange Free State, South Africa	470.0	March 1951 (31 Days)	Circular	24-foot diameter	Karroo shales	Concrete
Van Dyk Consolidated Mines, Ltd. Ventilation Shaft.	Far East Rand, Union of South Africa.	461.0	August 1941 (31 Days)	Circular (Cecilia type)	15-to 16-foot Diameter as sunk. 14-foot lined.	Witwatersrand Quartzite	Unlined as sunk
West Rand Consolidated Mines, Ltd. [1 2]	Western corner Witwatersrand, Union of South Africa.	454.0	May 1940 (31 Days)	Rectangular	6 compartment 37.5 by 13.5 excavated	Quartzite and shales	Timber lined
Water Lilley Shaft.	Eureka, Nevada.	427.5	September 1920 (30 Days)	Rectangular	Three Compartment. 5.75 by 15.5	Porphyry and Limestone	Timber sets
Crown Mines, Ltd. No. 18 Shaft.	Outskirts of Johannesburg, Central Rand, Union of South Africa.	390.0	July 1935 (31 Days)	Circular	19.6-foot Rock section.	Quartzite and shales	Timber sets

1. Concurrent sinking and equipping.
2. Mechanical mucking by air-operated grabs.
3. Actually 29 working days due to lost time in replacing one electric hoist with a steam-driven hoist.

of the size of the deposit, its value, the probable daily output of the mine, and the structural geology of the strata. Without this knowledge an engineer is helpless in planning shaft facilities. The method of shaft sinking is selected with special reference to the material that must be removed and supported, and to the labor power available. Bad planning can lead to inefficient sinking and a high cost.

Prospect Drilling.

The drilling program for a new orebody must not only supply geological data, but also data to be used for shaft planning and sinking. The program must provide detail information on the structure and the physical characteristics of the various strata through which shafts will have to be sunk. The presence of artesian waters and underground gasses can also be detected by diamond drilling. A knowledge of the thermal gradient is also of importance since it may be necessary to design the shaft for maximum ventilation if the thermal gradient is high.

Site of Shaft.

In the choice of a shaft location it is of major importance to have a thorough knowledge of the orebody, structural geology and surface topography. To keep the development cost down to a minimum a shaft should be as close as possible to the orebody. If the orebody is of gentle inclination it might warrant an incline shaft in order to cut down on the development and haulage cost. In this report,however,inclined shafts will not be discussed in detail. The distance between a shaft and an orebody will depend on the type of mining. In the case of block caving the shaft must be of sufficient distance from the workings to minimize the danger of caving the shaft.

The surface topography may also prove to be more favorable in certain places than others. Many hundreds of feet of shaft can be saved if the shaft is placed at the lowest elevation in a mountainous area. This will not only reduce the cost of sinking but also the cost of hoisting.

Orientation of shafts is also important to relieve rock pressure. In an area where the rock pressure is great it will be advisable to design a circular shaft since it has greater abilities to withstand rock pressure than other types of shafts. By orientating shafts with their long axis perpendicular to the strike of the bedding the least amount of stress will act on the shaft.

Size and Shape of Shaft.

The size and shape of a shaft depends on a various amount of factors.

1. Future or Present Working Conditions:

The future or present working conditions gives an indication as to the tonnage to be handled per day by the shaft or; the amount of air that must pass through the shaft per minute. Circular shafts offer the least resistance to air and it is therefore advisable to use circular shafts where a maximum amount of ventilation is required. In the case where a shaft must be subdivided rectangular shafts are preferred since they are easier to subdivide.

The capacities of rectangular and circular shafts compare very good and the final choice can only be made after all the disadvantages and advantages have been weighed.

2. <u>Purpose of Shaft.</u>

The purpose of a shaft is of great importance in the design of a shaft. Not only does the purpose indicate what type of shaft is to be used but also its cross-sectional dimensions. For ventilation the circular shaft is advisable since it has the lowest operating cost and the highest amount of ventilation. Circular shafts can be concrete lined much easier than rectangular shafts, which are to a great advantage in ventilation since it reduces the amount of water in the shaft. By reducing the amount of water the moisture content of the air is kept to a minimum, thereby promoting better cooling efficiency.

The purpose of a shaft will also determine its size. It is logic that the size of a shaft should not be greater than required. The future production of a mine will usually determine the size. The size of a shaft should be sufficient to handle the broken rock and the men and equipment necessary to break the rock.

3. <u>Depth of Shaft.</u>

In the original planning, stage hoisting must be taken into consideration if deep mining is planned on. Not only is it advisable to plan on stage hoisting if deep mining is considered, but it can be of great advantage in the case where a dipping orebody is present. By using stage hoisting in a dipping orebody it is possible to shift the position of the lower shaft closer to the orebody, thereby reducing the cost of driving drifts and the cost of haulage. Stage hoisting increases the cost of hoisting but this may be warranted by the reduction in development and haulage cost. Stage hoisting is also safer than the use of deep winding.

For a shaft of given cross-section the tonnage which can be hoisted varies inversely with its depth. For deep mines with great capacities this will be of considerable importance since the tonnage that can be hoisted will be limited. Most mining operators consider that 4000 ft. is the most suitable depth for operation. Deep winding is also limited and at present around 7000 ft. Deep winding reduces capacity and safety. If deep mining is probable the possibility of using stage hoisting must be taken into consideration and plans made accordingly.

For ventilation purpose the shaft should be sunk as deep as possible instead of in one or more stages. This will reduce the cost of sinking and increase the efficiency of ventilation.

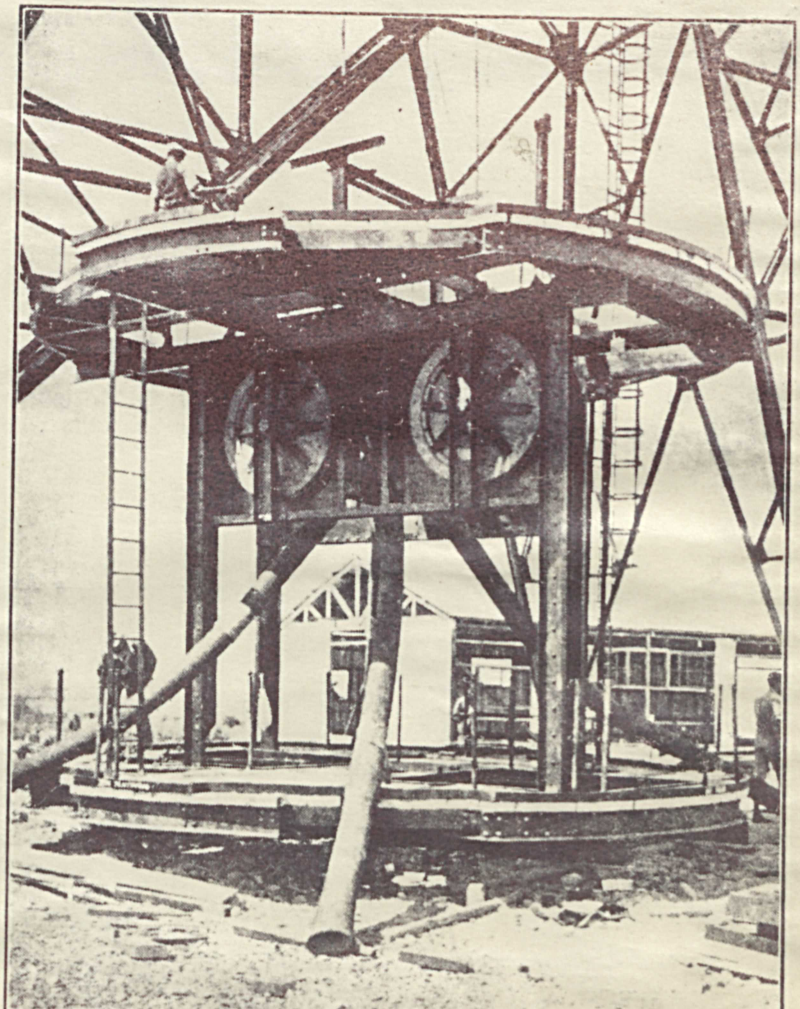
4. Ground Conditions.

Information on the ground conditions can be obtained by diamond drilling and are important in shaft planning. Circular shafts are preferred in heavy and bad ground. Concrete lining can be done concurrently with sinking operations thereby increasing sinking rate and safety. Effect of rock pressure is greater in rectangular shafts than circular shafts. Condition of ground also determines the distance which support may be lagging the excavation of the shaft.

Summary on Circular Shafts.

One of the greatest advantages of a circular shaft is its high efficiency in ventilation. Circular shafts offer the least amount of frictional resistance to air flow and creates a minimum amount of turbulence. Operating cost of ventilation is also considerably less.

Fig. 1 -- Picture of the Galloway Stage



Source -- South African Mining and Engineering Jour.; April 7, 1951

In order to keep air as dry as possible it is best to concrete shafts to prevent the ingress of water. Dry air has a better cooling effect on the human body and by keeping the air as dry as possible the comfort and efficiency of the workers will increase. Circular shafts can be sunk concurrently with sinking and more rapidly than rectangular shafts.

Over-all cost of sinking, equipping, maintenance and operating are less than for rectangular shafts.

The main disadvantage of circular shafts were that their capacities were less than for rectangular shafts. By increasing the size of the hoist, skips and winding speed, it has been proved that the capacity of a circular shaft can be increased to compare favorably with the capacity of a rectangular shaft.

During the last few years engineers in South Africa have overcome the disadvantage of not being able to equip circular shafts concurrently with sinking by the development of the "Galloway Stage".[2]

Prior to this new development circular shafts were sunk for a distance of 60 ft. and then suspended to concrete-line the shaft. This was time consuming and the main reason for the development of the Galloway Stage.

<u>The Galloway Stage</u>.

Figure No. 1 is a view of the two-deck Galloway stage which played an important part in establishing new world records in shaft sinking. The following is a description of the operation of the Galloway stage as described in the South African Mining and Engineering Journal, April 7, 1951.[2] "The stage is

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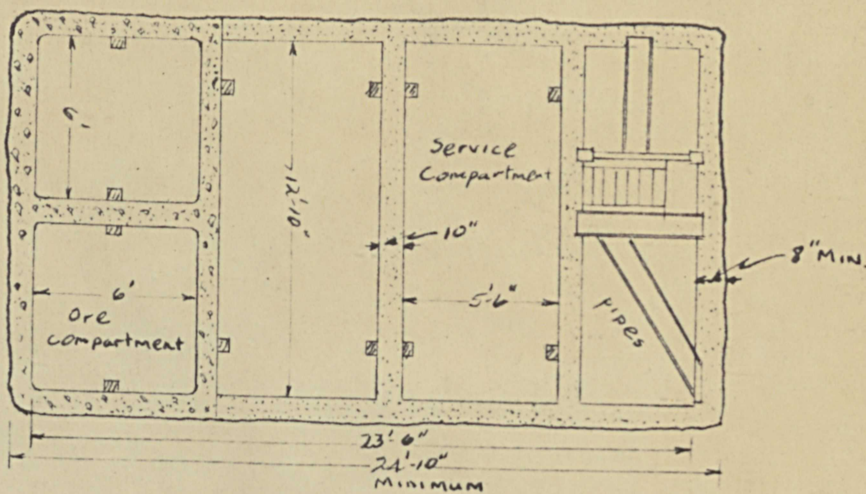
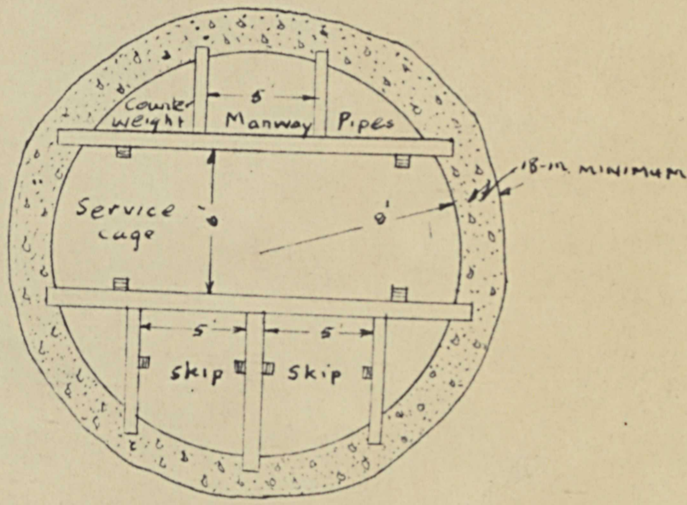
2 .... "The Shaft-Sinking Record at Virginia," South African Min. & Eng. Jour., v. 62, n. 3034, April 7, 1951; p. 177.

Fig. 2
Cross section of United Verde No. 7 shaft



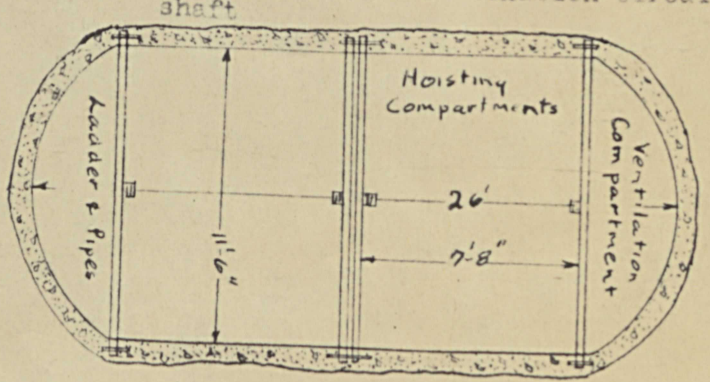
Source - U.S. Bureau of Mines, Bul. 357, 1932

Fig. 4. -- Cross section of circular shaft



Source - U. Bureau of Mines, Bul. 357, 193?

Fig. 3. -- Cross section of combination circular and rectangular shaft



Source- Robert peale, Mining Engineers Handbook, 1952 suspended on two ropes, one of which passes around the two sheave wheels shown and the other around their counter-part on the reverse side of the partition. In its completed form the stage is equipped with a built-in concrete distribution box, and three of the four rubber pipes are clearly shown. The Galloway stage, suspended above the shaft sinkers, facilitates simultaneously drilling, mucking and hoisting (through spaces shown in the two decks of the stage) with the operation of forming the shaft lining with concrete."

Cross-section of Shafts.

The cross section of a shaft is determined by the use to which the shaft is to be put and the material through which it will be sunk. Its size and number of compartments should be such that the mine tonnage of ore and waste can be hoisted without difficulty in the time available and the men and supplies can be hoisted promptly. Ventilation is also important and the size should be such that the required amount of ventilation could be obtained.

There are four basic types of shafts; 1. Rectangular, 2. Circular, 3. Elliptical and 4. Octagonal. Types 1 and 2 seem to be the most used with the trend towards circular shafts. In Butte, Montana, the octagonal shaft is favored strictly for ventilation purpose. Rectangular shafts have the best all-round use and used to be the predominant type of shaft. As a result of the development of new techniques in sinking circular shafts there appears to be a tendency towards more circular shafts.

Figure 2 is an example of a rectangular cross section of a shaft, as used by the Verde Copper Co., Jerome, Arizona. The depth of the shaft is 5000 ft. with a capacity of 3000 tons/day and hoisting of men and supplies.

Figure 3, an example of a combination circular and rectangular shaft, illustrates easy subdivision for, hoisting and ventilation.

Figure 4 represents the cross section of a circular shaft and its subdivision.

During the last few years shafts are being designed with large cage compartments so that loaded trucks with timber and equipment can be lowered directly. It has the further advantage that big equipment can be lowered without disassembling them.

SINKING PLANT.

Temporary Sinking Plant.

In the past it was customary to erect a temporary sinking plant for sinking operations. As a result of an increase in the sinking rate and the use of mechanical muckers it now has become necessary to increase the size of the hoists and sinking equipment. A greater amount of materials and broken rock has to be hoisted and it might cut out the possibility of using a temporary sinking plant. Where mechanical mucking is used and where rapid sinking is required, it will thus be to a great advantage to erect a permanent plant instead of a temporary plant.

Temporary sinking plants consist of: hoisting apparatus; headframe; provision for rock disposal; ventilation equipment; water disposal equipment; compressors; housing and accessories. The capacity of the sinking plant should be sufficient to handle the required amount necessary to promote efficient sinking.

The temporary plant should be of such a design that it will not interfere with the erection of the permanent plant, except during the change over. The design is usually of such a nature that they may be erected, disassembled and transported easily.

The main advantage of a temporary sinking plant is that it allows the erection of the permanent plant concurrently with the sinking operations. Main disadvantage is that for rapid sinking the facilities of a temporary sinking plant may not be sufficient to handle the disposal of the broken rock in the time allocated.

If a shaft is sunk for ventilation purposes only, a temporary sinking plant will be sufficient.

Permanent Hoist and Headframe.

A permanent hoist and headframe are usually bigger than a temporary sinking plant. With a permanent plant it will thus be possible to handle more material and men in less time. The permanent plant should be used where possible and erected as soon as possible where a temporary plant is used. The use of a permanent plant not only promotes rapid sinking, but also increases the efficiency.

Rapid sinking methods require greater rock disposal capacities and heavier hoisting apparatus in order to operate efficient. Sinking equipment is also heavy and requires a stronger hoist to cope with it.

The design of a permanent plant will depend on the depth of the shaft, the required capacity and probable daily output of the mine.

SHAFT SINKING

Routine.

To promote efficiency in shaft sinking, organization and planning must be of high quality. South Africa gives us an excellent example in shaft-sinking organization and planning. By increasing the efficiency of organization and planning they have been able to break one world record after another. The latest of 763 ft. per month is remarkable. This achievement was due to the efficient organization which led to an increase in the number of cycles per 24-hours from the usual three to four cycles. By cycle we mean drilling, blasting, mucking, ventilating and equipping of shaft by one crew. The entire operation of drilling, blasting, mucking and equipping was completed every 6 hours. In order to maintain such a rigid schedule, organization must be perfect and machines efficient.

Operations in sinking shafts are usually continuous over 24 hours per day. The usual amount of cycles per 24-hours are three, with three crews. Each crew is responsible to complete the entire cycle in 8 hours. Each crew will then have a rest period of 16 hours. In the Monarch shaft of West Rand Consolidated Mines, Ltd., South Africa, four crews were used instead of the usual three. Each crew worked for 6 hours and then rested for 18 hours. Average time for completion of entire cycle during September was 5 hours and 23 minutes.[3]

In the Virginia No. 3 shaft, South Africa, the number of crews was increased to four but the number of cycles per 24 hours remained three.[4] The reason for the increase of crews is to give the workers a 24-hour rest period instead of the usual 16 hours to increase their efficiency.

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[3] ....., Mining World, December, 1955

[4] ....., South African Min. & Eng. Jour., April 7, 1951.

Main disadvantage of using a rigid cycle schedule is that it is strenuous on the workers and a small mistake can result in the missing of a round.

Common practice, followed by most operators where rapid sinking is not stressed to a great deal, is to operate on a three shift basis per 24-hours. Each shift completes the work on hand and does as much as possible. This method requires men of wider experience and training but a less rigid schedule can be followed, relieving the strain on the workers.

Where concurrently sinking and equipping are done the crews for each cycle usually consist of the following:

<u>Supervision</u>

1 master sinker

1 shaft foreman

1 support foreman

<u>Shaft Crew per Cycle</u>

Sinkers

Drillers

Muckers

Timber or lining men

<u>Surface Crew per Cycle</u>

Pipemen

Electricians

Fitters

Hoistmen

Rock Disposal men

DRILLING

Drills

Various types of drills are used in present day sinking. The hand-held drills still seem to be the most popular. The common types of machines used are the jackhammer, the mounted drifter and the heavier sinkers. The most popular drill appears to be the 75-lb. 3-in. jackhammer and is universally used. The advantages of the jackhammer is its quick set-up time, flexibility and efficiency with high-priced labor. Mounted machines are time consuming and have less flexibility. The set-up of mounted machines can also be cumbersome in circular shafts; In Europe frames have been designed on which machines are mounted to command the entire shaft. This is not suitable for mechanical mucking, since time is consumed by raising and lowering the frame.

Spare machines must be kept in case of breakdowns during shifts. All machines should be kept well lubricated and be checked often to maintain the best operating efficiency.

Steel

One-inch hexagonal steel appears to be the most used steel in modern shaft-sinking practice. Bit size of 1 5/8 in. and 1 7/16 in. are advisable with a bit size reduction of 1/16 in. to ¼ in. per change. For hand-held machines a steel change of 12 in. is preferred and for drifters from 18 in. to 36 in.

The ordinary cross-bit used to be used but tungsten-insert-tipped bits seem to be gaining ground in its uses. Tungsten bits are faster and more efficient in hard ground.

Drilling Accessories

Where a large number of drills are to be used it is necessary to use a type of manifold to distribute the air and water to the machines. A manifold is a device used for rapid connecting of air and water to a large number of machines. It allows an efficient way of connecting all drills and distributing compressed air and water. It is connected to the main air and water line and sprouts-out to the desired amount of connections required for the drills.

Air and water lines should be of sufficient diameter to supply the required amount of machines without a drop in pressure. Diameter of the pipes will depend on the number and size of machines used. To prevent delays in drilling, hoses should be of sufficient grade to withstand rough handling. Oil-liners should be attached to lubricate all drills in order to ensure efficient operation, and a minimum of maintenance.

During recent years it has been the practice in South Africa to use a device to indicate the outer and inner holes of a circular shaft. The placement of holes are of great importance in rapid sinking since one misplaced hole might be sufficient to bind the sinking stage and cause a serious delay. The device used pivots on a center-pin equipped with a universally-jointed arm with drill-guides to position the outer and inner holes; Chains suspended from the arm indicate the position of the intermediate holes. By using this device drilling takes place in a definite pattern, and all machines start and finish in about the same time. In this way the allocated time is used to the best advantage.

SHAFT ROUNDS

The types of round used vary from place to place and also in the same shaft. Best type of round cannot be readily determined

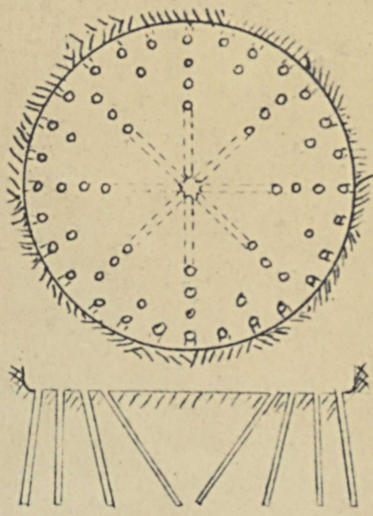


Fig. 5 -- Pyramid Cut in Circular Shaft

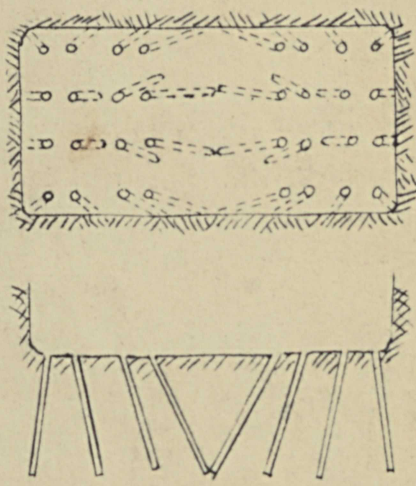


Fig. 6 -- V-cut Shaft Round

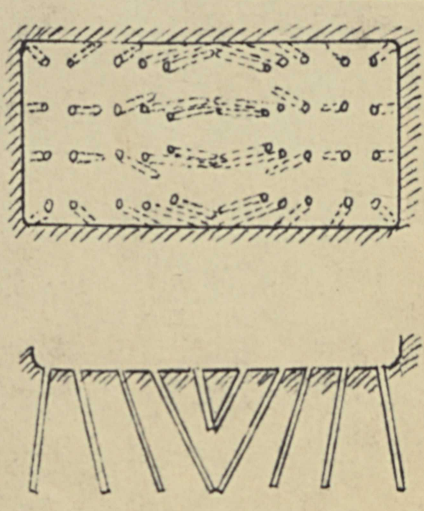


Fig. 7 -- Double V-cut Shaft Round

Figure 8. Bench Cut

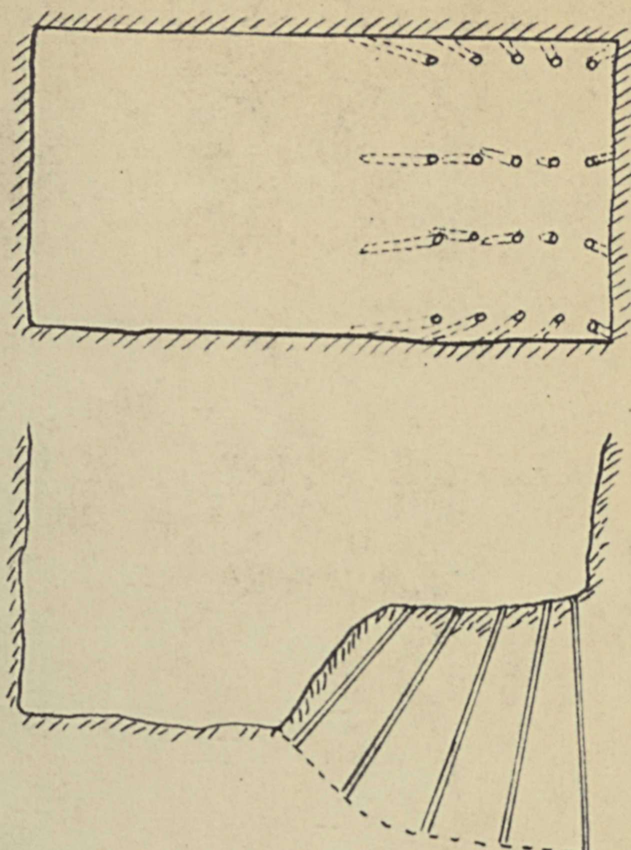
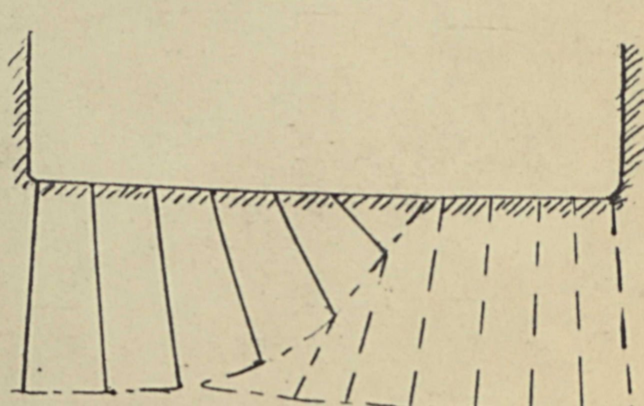


Figure 9. Elevation Showing Two Sucessive Rounds With Bench Cut



without trial, although experience is of great help. The type of round depends on the character of the ground and the cross-section of the shaft. Depth of round rarely exceeds the width of the shaft and is considered to be limited by the width. Where a fixed routine or cycle is used the depth is limited by the amount of broken rock that can be disposed of in the allocated time.

For ground that breaks easily the <u>V-cut</u> type is the best suitable round. If deep rounds are to be drilled or if the ground breaks hard it may be necessary to drill auxiliary cuts or the <u>Double V-cut</u>. V-cut rounds can be altered to a great deal and it is this flexibility which makes it the most used. The disadvantage of V-cuts is the possibility of dangering shaft timber, where used, by flying rocks. This could be eliminated by using a blasting shutter to protect the timber. The <u>Pyramid cut</u> is a modification of the V-cut and is generally used in circular shafts. Figures 5 to 7 illustrate types of V-cuts used in practice.

<u>Bench cut</u> is used in hard and wet ground. It has the advantage of always having two free faces to break to. The cut alters from side to side in the shaft with subsequent less danger to damage timber. The bench cut is advisable in shafts with a great amount of water since it leaves a natural sump and a relatively dry bench for the workers to work on. The bench cut reduces hand mucking when mechanical mucking is used since the remainder rock on the bench can be blown into the sump with compressed air. Chief disadvantage of bench cuts is that only half of the shaft bottom is blasted, causing slow sinking. Figures 8 to 9 illustrates types of bench cuts.

In the past the depth of a round was limited to a great extent by amount that could be mucked in a fixed schedule. By the development of mechanical mucking it is now become possible to increase the depth and still muck-out in the allocated time (if cycle system is used). Where cheap labor is available it is also possible to increase the number of muckers per shift and thereby the amount of broken rock that can be handled in the allocated time. In Africa it is possible to increase the number of muckers to such an extent that their mucking capacity may even be greater than mechanical mucking.

The number of holes per round depends on a various number of factors; the size of the shaft; the ease of breaking the ground; type of fragmentation desired; type of round used and the depth of the round. It is logic that for handmucking fragmentation should be much smaller than for mechanical mucking. Average advance per round drilled appears to be between 5 ft. and 7 ft.

Pilot Holes

If there is a possibility of the occurrence of water-bearing fissures it is advisable to drill pilot holes during each round. Pilot holes vary in depth from 10 ft. to 40 ft. and depend on the possibility of encountering water within the next few rounds. Water can be of a serious extent in shaft sinking and also dangerous. If their presence is known beforehand steps can be taken to cement the fissures. If water is encountered during the drilling of the pilot holes the pilot holes can be sealed and cementation can be applied.

EXPLOSIVES AND BLASTING.

Explosives

The most economical size of explosives for hard rock is 1¼ in.

by 8 in. and this will require a drill hole of slightly greater diameter. Blasting in shafts demands much greater care as far as drilling the round and the selection of explosives are concerned than in drifts or raises. Great care must be taken in timbered shafts to eliminate the possibility of damaging the shaft timber. Most shafts are wet, either as a result of ground waters or water from the drilling operations, and it is, therefore, necessary to use a water-resistant explosive. Gelatine dynamite is generally used because of its water-resistant properties, its high loading density and good fumes.

Grade of explosive used depends on the following factors;

1. Type of ground.
2.. Size of rock fragmentation desired.
3. Depth of round to be pulled.
4. Burden on holes.
5. Type of detonation.
6. Type of explosive used.

An explosive with a high rate of detonation usually breaks the rock better than a slower powder; thereby increasing the efficiency of rock fragmentation. Holes should only be loaded with the required amount of powder and correspond with the grade of powder used and the rock fragmentation desired.. The highest efficiency explosive can only be found by trial. To increase explosive efficiency holes should be well tamped and stemmed.

The amount of explosive used per foot of advance varies considerably and ranges from 10 to 70 lbs. The amount used depends on the quality of the ground, grade of the powder, cross section of shaft and the depth of the round drilled. Powder consumption in shafts is generally greater than in drifts since an extra amount of powder is needed to lift all of the broken rock and produce better fragmentation.

Primers

Electric detonators are the safest primers that can be used since the entire crew can be hoisted before the blast is set off. by throwing the switch. Failure of the hoisting equipment can be of great danger to the sinking crew in a shaft if ordinary fuse is used and already ignited. Electric detonators are safer and the possibility of misfires due to water is reduced. Great care must be taken to see that delays are loaded in the proper order or a great amount of misfires may occur. Incorrect wiring in electric blasting may also lead to an incomplete blast, resulting in a delay in sinking.

Standard delay electric blasting caps used to be the most used. After the development of "Milli-second" blasting caps it was found that by using "MS" delays better fragmentation could be obtained with a reduction in powder consumption. In general practice delays from No's 0 to 8 are used. Number of delays required depends on the number of holes and the fragmentation desired. Best results are obtained by using either a straight parallel or a parallel series connection. Series connections are likely to result in shorts in the presence of water which will result in a poorly pulled round, a delay in sinking and possibly a serious accident. Stray currents are also dangerous in electric blasting since it may cause the accidental detonation of the caps.

Best position for primers appears to be at the bottom of the holes since the danger of cut-offs are less likely to result. Primers should be made on surface and sent down when necessary.

Wiring Rounds

Great care must be taken in wiring the round. Best all-round connection is in parallel, which not only simplifies the work, but is also safer. Where parallel wiring is used two bus wires are strung across the bottom of the shaft, and the individual detonators are connected to the bus wires by twisting the bare leg wires to each of them. Care must be taken not to connect both leg wires to the same bus wire.

A permanent firing line is usually strung down the shaft by the electricians and are at a sufficient distance from the bottom of the shaft to ensure that no damage occurs during blasting. After the detonators are connected to the bus wires the bus wires are connected to firing wires by inexpensive wires. Connection wires should not be used more than once. After wiring in the shaft is completed the men are hoisted to surface. The firing line should not be connected to the power line until the entire crew is hoisted. The man in charge of the blasting operation then connects the firing line to the main current and throws the switch which sets off the blast. The switch must be kept under lock and only the man in charge of the blasting should have the key. The strength of the main current must be sufficient to ensure the detonation of all blasting caps and will depend on the number and resistance of the blasting caps used.

After the blast sufficient time must be allowed for the fumes to clear and is layed down by law in some places. In South Africa, government regulations require a minimum of 30 minutes after a blast before re-entering any place.

SHAFT MUCKING

Introduction

Removal of the muck broken by blasting is a major problem and time consuming. Although tremendous strides have been made in mechanizing shaft mucking, the critical point in the shaft sinking cycle is still within the mucking phase.

The broken rock must be loaded, either by hand or mechanical device, into buckets for hoisting to surface. Speed in shaft sinking is becoming more and more prominent, thereby increasing the pressure on efficient mucking operations. The old method of mucking by hand is dieing out and replaced by mechanical mucking. Mucking by hand is still practiced in countries, such as South Africa, where cheap labor is available. Mechanical mucking devices are still far from 100% effective, but great strides have been made in obtaining this goal. Some new developments prove to be very successful and efficient.

In South Africa, due to the cheap labor available, hand mucking is still favored and used to an advantage. The idea is to use as many men as possible to remove the spoil. By using a great number of muckers speeds have been obtained in shaft sinking that even leaves mechanical muckers behind.

Most mechanical muckers require a sinking platform or stage to operate from. As a result of greater capacities in mucking larger hoist are advisable with permanent surface installations. Most mechanical muckers require extra hoists and power to operate. The added cost, however, can soon be made up as a result of a decrease in labor power.

Hand Mucking

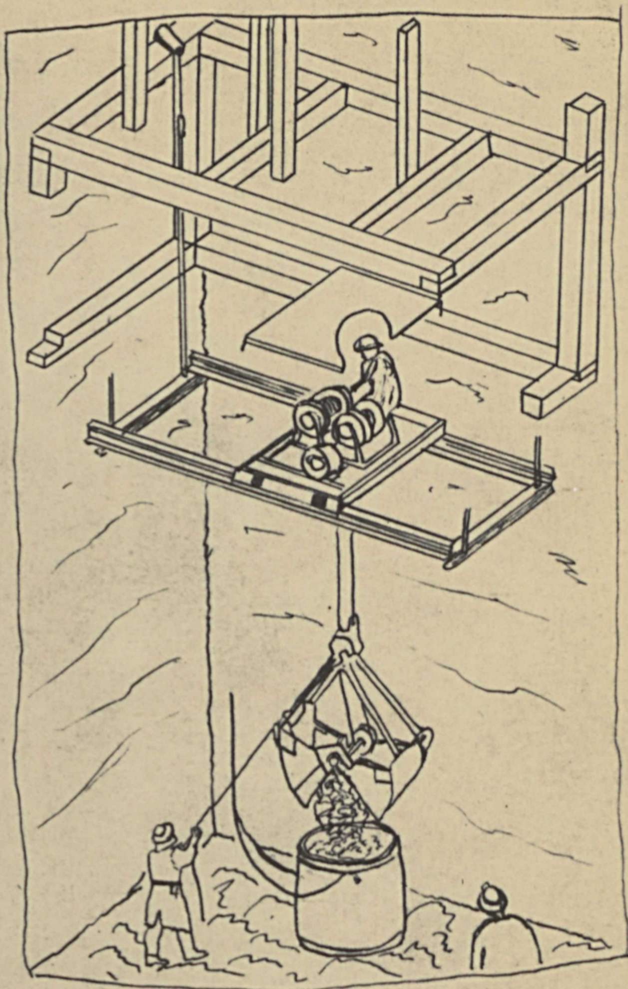
The oldest method of shaft mucking is by hand and requires a lot of effort. Men for hand mucking are hard to find and this method is now only used where cheap labor is available. Main reason for turning to machines in mucking is the cost of hand mucking. In South Africa, where cheap labor is still available, they believe in numbers for fast hand mucking. As many as 60 muckers have been employed at the bottom of a shaft at the same time. It is amazing how such a great number of muckers can be used. The negroes, however, being a race of rhythm accomplish the task with ease. Mucking is done in rhythm and no collisions occur.

In most South African shafts four 3-4 ton buckets are used, two hoisted while two are being loaded. No time is lost by waiting for the return of empty buckets. With increased depth of shaft the problem of waiting for buckets to return may become prominent. A "rule of thumb" is used in South Africa to overcome the effect of depth. The rule being as follows: "With a 3 ton bucket the optimum depth is equal to the rope speed". While this relationship is held no time is lost in waiting for empty buckets.

It is of interest to note that the present world's shaft-sinking record was established by using hand mucking. In establishing this record twenty-six muckers removed 120 tons of rock in 2 hours and 35 minutes. This is a rate of approximately 1.8 tons per hour per man. We see thus that the rate of hand mucking is not as slow as one would think. Actual time required to muck out entire round is less than with mechanical muckers.

A method used in olden times and even still today is to load the rock into auxiliary pans. These loading pans are then hoisted by a little tugger and dumped into skips or cars. The loading pans are open at one end or side to facilitate filling by shovel. The pans are loaded while skips are being hoisted or lowered to

FIG. 10 -- RIDDELL MUCKER



Source -- Min. Eng. , vol. 5, no. 8, Aug., 1953 save time.

The idea of loading into auxiliary pans while hoisting is now used in combination with mechanical muckers to save time.

Mechanical Mucking

A. Riddell Mucker.

The Riddell mucker was developed in 1942, to speed the expensive task of shaft mucking. Although it proved to have its faults the task of mucking was eased enormously.

In essence, the Riddell mucker consists of a clamshell bucket suspended by cables from a steel carriage. The clamshell bucket is operated by an air hoist mounted on the steel carriage moving on a steel frame, resembling a conventional crane track. Fig. 10 shows the Riddell mucker in action.

Since the first mucker was built new ideas have been incorporated in the present used machine. Modern improvements include a heavier built machine to withstand blasting against it. Circular tracks have been designed to improve its efficiency in circular shafts. For large rectangular shafts the Riddell is a designed to obtain a cross motion.

The clamshell loads directly into the buckets, leaving the last 3 to 5 in. of muck at the bottom of the shaft for hand mucking. A 31-cu.ft. bucket can be loaded in 1½ to 2 minutes. A certain amount of water will also be dumped into the buckets decreasing pumping.

Disadvantages of Riddell mucker are:

1) No positive action in digging.
2) Large chunks of rock can get stuck between claws causing spoil to fall out.
3) Clamshell has to be guided at bottom of shaft.

Fig. 11 -- Low-head Hydro-mucker
Open Position

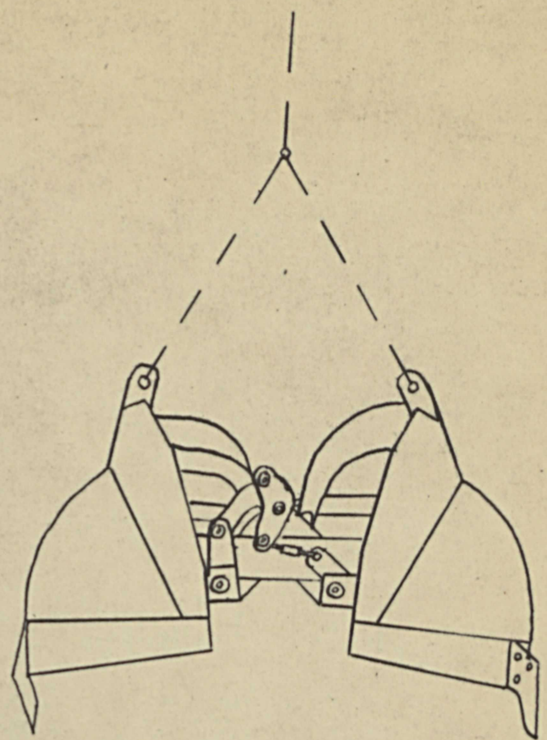
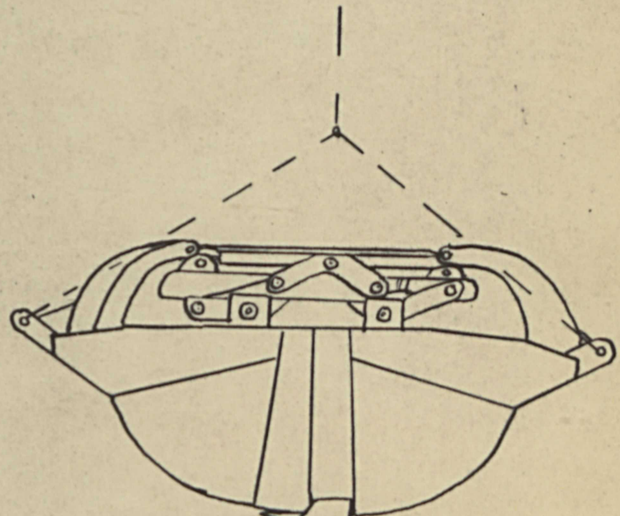
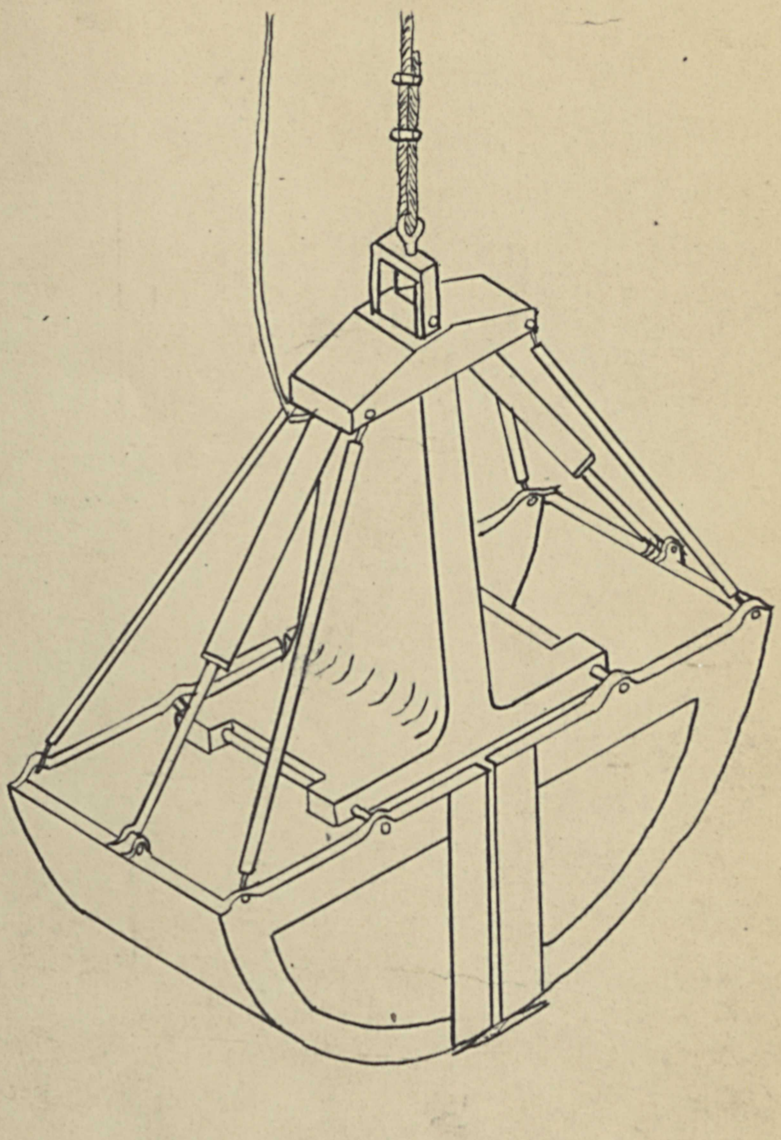


Fig. 12 Low-head Hydro-mucker
Closed Position



Source -- H.W. Foss, Shaft-sinking Investigation, 1954

FIG. 13 HI-HEAD HYDRO-MUCKER



Source -- H. W. Foss, Shaft-Sinking Investigation, 1954

B. Low-head Hydro-mucker.

The low-head hydro-mucker is basically of the same design as the Riddell mucker except that it differs in the type of power used to open and close the jaws. Hydraulic rams are mounted horizontally on the clamshell to lower the center of gravity, thereby giving the clam greater stability. These hydraulic rams give a positive type of action on the claws of the clam. Fig. 12 is a sketch of the low-head hydro-mucker, showing the position of the hydraulic rams. Main advantage of the low-head hydro-mucker is the greater ease that it can be operated. Two men at bottom of shaft can handle a 3/8-cu. yard clam with ease. The hydraulic rams also have a greater closing force on the clams than is the case with the Riddell mucker.

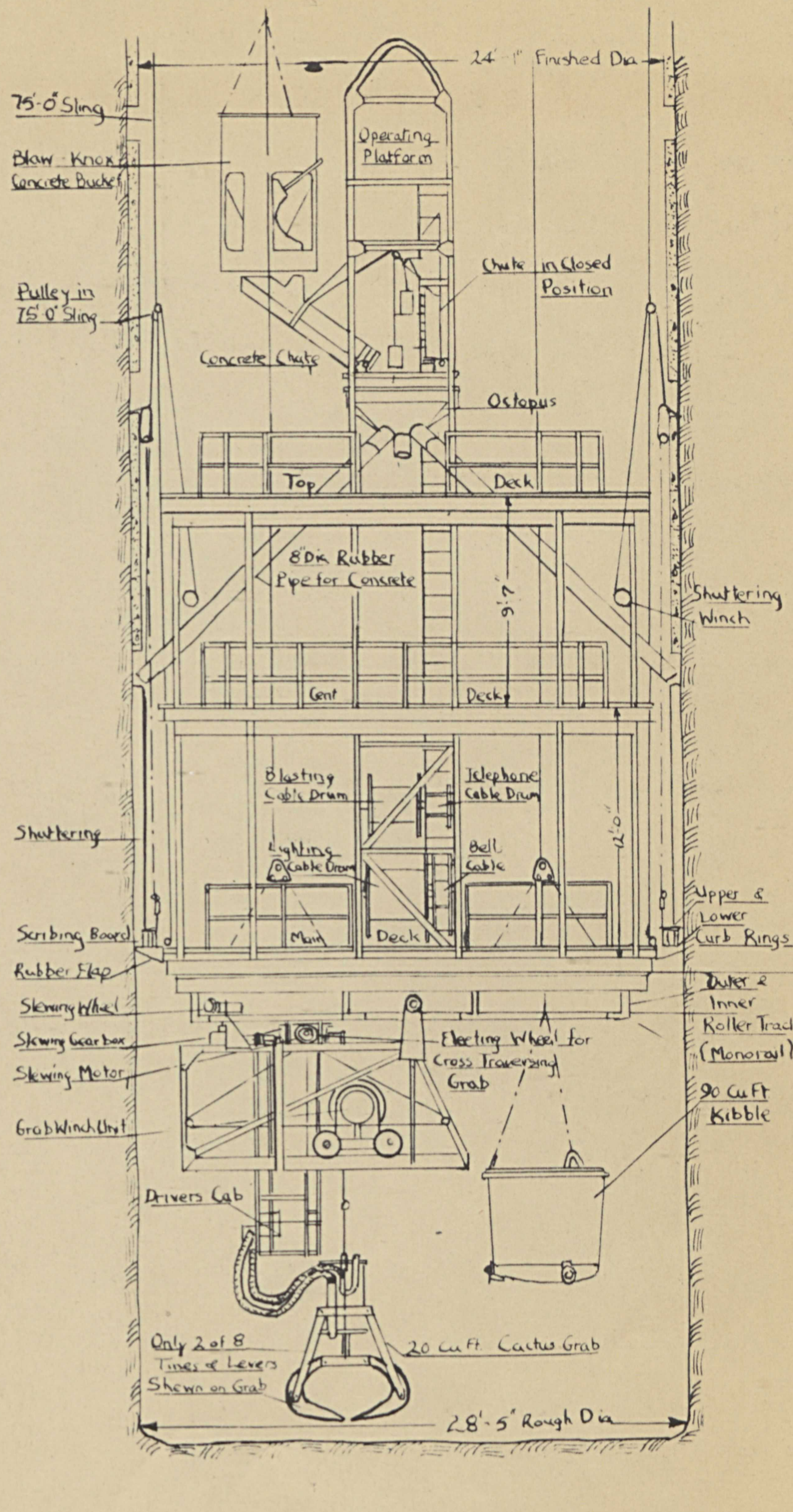
C. High-head Hydro-mucker.

The high-head hydro-mucker is shown in Fig. 13. Instead of the hydraulic rams being mounted horizontally, as in the case of the low-head hydro-mucker, they are at an angle. Due to the position of the hydraulic rams the mucker lacks the stability of the low-head hydro-mucker. The high-head hydro-mucker has the same advantage as the low-head hydro-mucker over the Riddell in that a greater force is exerted on closing the jaws. The possibility of not closing is thus limited.

D. "Cactus"-type Mechanical Grab.

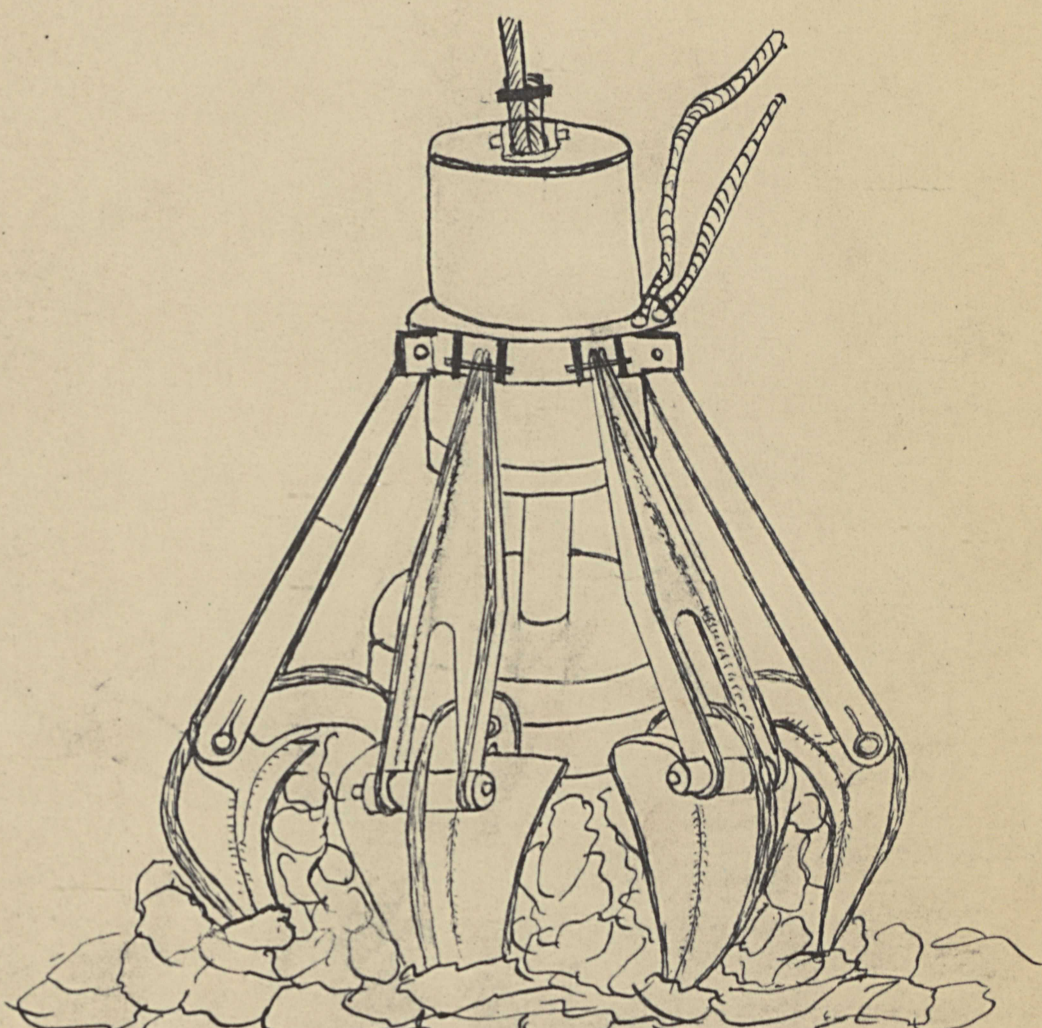
The air-operated grab was developed by the engineering staff of the Vlakfontein Gold Mining Co.,Ltd. and used successfully to establish a new world shaft-sinking record during the month of May, 1953. Record speed is attributed in part to the grab which saved approximately half of the usual labor force required to clear the bottom of the shaft.

Fig. 15. Diagram of Galloway Stage and Cactus Grab Mucker



Source -- Can. Min. Jour., vol 7, no. 3, pp. 66: March, 1954

Fig. 16 -- Cactus Grab



The grab consists of eight, tungsten carbide tipped claws, each of which forms a segment of the flasklike shape the grab assumes when closed. Open, the grab has a span of 9 ft. with a capacity of 20-cu.ft. of rock. The grab is operated by one man from his seat attached to the grab headframe, giving him an uninterrupted view of the shaft bottom. Fig. 16 is a sketch of the grab. The grab is capable to load 90-cu.ft, 5-ton buckets in about 3 minutes and hoist 100 tons per hour.

The grab is used in combination with the three-deck Galloway stage. Sinking and lining operations can thus be done concurrently (see Fig. 15).

The Cactus grab has better loading ability as a result of its multi-point jaws and positive closing action of the jaws. Greater capacity and digging force thus makes the grab more desirable than the Riddell and Hydro-muckers.

E. "Grab" Shaft Mucker

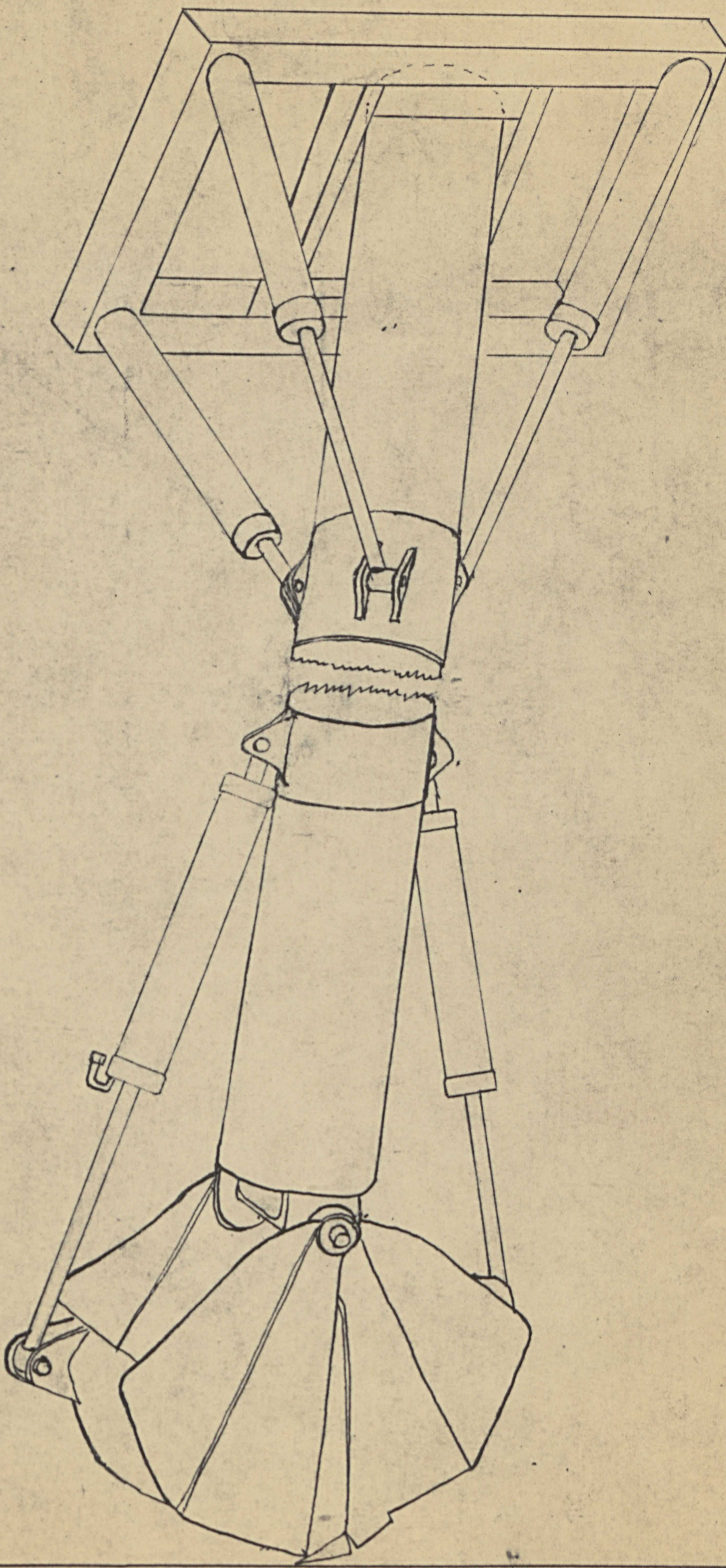
The grab was developed by C. McLauchlan, E. A. Jahns, and H. Carlstein of the Anglo American Corp. It is intended to give a positive closing action on the jaws with full downward pressure on broken rock. Main operation is the same as the Riddell except the power-operated jaws.

The Grab consists of two jaws that rotate on pivot bearings attached to the cylinder wall. A pin inserted in the upper end of the piston rod is housed on each end by G.M.shoes which ride on guides. Piston rods transmit the force to the link arms which actuate the jaws.

Important design features are:

1. The maximum closing force transmitted to the jaws

Fig. 14 -- Cryderman Mucker



as a result of the horizontal link arms.

2. Use of two fixed pivots on each side allows for wide opening of the jaws and for maximum loading with only a shallow bite.

One load can be mucked every 30 seconds. Two grabs have mucked 275 tons in just under four hours.

F. Cryderman Positive-Action Mucking Machine.

The Cryderman mucker is the latest development in mechanical mucking. The basic design was done by Mr. Warner Cryderman, a well known mining man of Canada. The first firm to experiment with this machine was the shaft contracting firm of Pogue and Vendetti. Along with Mr. Cryderman they solved some of the design problems during the initial experimental development stages of the machine.

The Cryderman mucker consists of an air-actuated clam attached to a telescopic boom. The boom can be directed and controlled by swing air-cylinders around the center pivot point. The air-operated machine is mounted beneath the deck of a standard mine cage suspended through a gimbal-type support. One man can control the swing sylinders through a two-lever positive control.

Mucking operations require two men at bottom of shaft to spot and switch buckets. One man is needed to operate the machine. A 22 cu.ft. sinking bucket can be loaded in little over 1 minute.

Fig. 14 is a sketch of the Cryderman mucking machine.

Operating advantages of Cryderman mucker are:

1. Not necessary to suspend machine from timber.

2. Machine can be used to muck station cuts, since it can extend as much as 8 ft. beyond line of shaft.

3. Can be operated in vertical and incline shafts.

4. Can be hoisted as one unit with ease.

5. No cables, sheaves or hoist needed to operate machine.

6. Machine is under positive action at all times, requiring no force of gravity for digging.

G. Mucking by Tractor Crawler.

A new technique for loading broken rock in the bottom of shafts has been developed by shaft-sinking contractors by using the Eimco 630 crawler.

In order to provide a natural face at the bottom of the shaft the bottom is blasted in the shape of a "V". The Eimco is lowered immediately after the blast and proceeds to muck out the round into 3-yard tubs. Yime for loading varies, but with experienced crews is below 2½ minutes.

Main advantage of using the Eimco is the elimination of expensive equipment used in shaft-sinking operations alone. No special timber, guides or hoist are needed. After shaft is completed the Eimco can be used in mucking out drifts on production loading.

Another method is to blast the bottom of the shaft in two separate blasts, i.e., bench round, thus piling in one end the rock from the other end.

SHAFT SUPPORT

Introduction

Shaft support serves a dual purpose - to support the walls and to afford support for guides, ladders, pipes and cables. In good solid ground the shaft may be lined only for the support of guides, pipes and ladders.

In the old days shafts were supported in many ways, some were timbered, others were lined with brick. Today shafts are still supported by timber; however, since concrete has become in general use it has almost entirely replaced the older and more expensive form of masonry lining. In many cases shafts are first lined with timber and then later replaced by concrete. With modern developments in concreting this is becoming unnecessary and the shaft may be lined with concrete initially. In the Kelley shaft, Butte, Montana, the shaft was raised and timbered; concreting replaced the timber after the shaft was completed. In this instance it was easier to timber first, since the shaft was raised. In South Africa the practice is to concrete the shaft concurrently with sinking-operations.

The cost of lining or supporting a shaft is high and it is of great importance to design the best method. The initial cost of lining a shaft with timber is less than to line it with concrete or with steel support. Trouble with timber is the high maintenance cost. Timber decays readily and is subject to wear faster than concrete. In concreting a shaft the initial cost is slightly higher than timber, but since very little wear is encountered the cost over a period of years is definitely less.

Concrete linings are intended to provide a skin cover to excavated ground and so prevent peeling or flaking due to exposure to atmospheric conditions, as well as to facilitate the placing of shaft equipment. Linings of concrete are more rigid and less likely to bend and lose alignment. Concrete, however, should not be used in ground which is suspected to move, as it will be crushed and it is expensive to replace. Timber is preferable, as jacket sets may be used to ease the work of replacing broken timber.

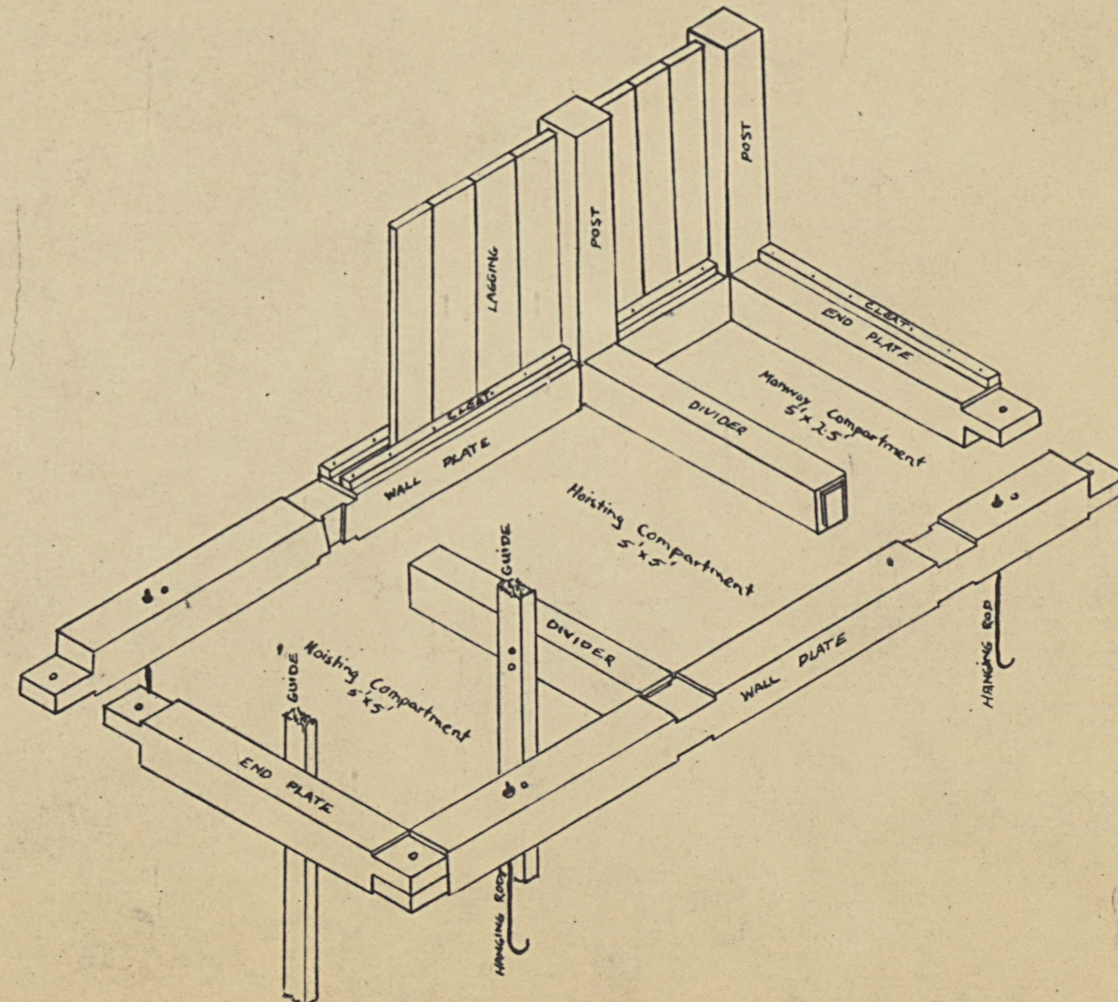


Figure 17. - Details of Hope shaft timbering.

Source -- U.S. Bureau of Mines, In. Circ. 7426, pp. 5, Jan., 1948

In cases where the shaft is designed for ventilation purposes concrete is preferable and offers great advantages. Latest practice is to sink circular shafts for ventilation, as it offers less resistance to air flow. Circular shafts can be more conveniently concrete lined. Concrete linings prevent the ingress of water, thereby increasing the cooling effect of air by preventing an increase of the humidity. By preventing the ingress of ground water in a shaft, pumping cost is also kept to a minimum.

Steel sets can be used in shafts that are free of acid water and have a longer life than timber. It has the added advantage of being fireproof. Cost of steel linings are expensive and they are not used to a great extent. Water also has a corrosive action on steel. Concrete having no corrosive effect is the most desirable support in wet shafts.

Timber Linings.

Shaft timber is usually constructed of 8 by 8, 10 by 10, or 12 by 12 inch timber. The size of the timber depends on the amount of support required and on the use to which the shaft is to be put. For ventilation purpose timber must be of sufficient size to support the ground only. For high speed high tonnage shafts timber has to be more substantial to withstand the shock and vibration caused by hoisting.

Shaft sets are ordinarily placed at 5-ft. centers, although this distance varies from as much as 7 ft. to 4 ft. depending on ground conditions. In extreme cases solid cribbing may be required in bad ground, if timber instead of concrete is used.

Timber in shafts is subjected to decay. It is therefore necessary to use timber of high quality which is also treated with a preservative to prolong its life. Oregon fir is usually preferred for shaft timber, due to its higher qualities such as strength and reistance to decay. Where a long life is required and strength of minor importance Redwood is sometimes used.

Preservatives used to treat timber are: creosote, zinc chloride and arsenic. Most workmen have a dislike in treated timber, since it causes burns.

Timber being a fire hazard should be made fireproof if there is a possibility of fire. Guniting usually serves the purpose of making timber fireproof.

Fig. 17 shows the timber details of the Hope shaft, Clark Fork, Idaho. Main pieces of sets consist of 10 by 10 in. timber. Time required to place one set averaged 20-man-hours, and lining required an additional time of 3 man-hours.

In timbering shafts the bottom of the shaft should not be too close to timber in order to protect shaft timber from damage during blasting. Minimum distance of timber from bottom of shaft should be more than 20 ft. In bad ground, where it may be necessary to carry timber closer to bottom of shaft, blasting sets must be used to protect the timber from blasting. It consists of unframed timbers the same length and width of the horizontal members of the shaft sets. These blasting timbers are attached to the shaft timber and dropped to the bottom before the new timber is installed.

Bulkheads are favored in some localities since it serves a dual purpose -- to protect the shaft sets and to serve as a platform for timber men when they install new timber. The bottom of the bulkhead is protected by steel sheets. If further protection is needed steel rails may be bolted to the bulkhead.

As timber sets are placed they are suspended from the timber above with hanging rods 3/4, 7/8, or 1 inch in diameter. These rods tie the sets together and prevent settling of sets in case blocking becomes loose. In order to prevent the settling of an entire unit of shaft sets, bearing sets are placed at regular intervals to provide a solid support for the hanging timbers. Sills used in timbering stations usually serve the purpose of bearers. Bearers are placed across the shaft under each cross member of the respective set. To provide a solid base for the bearer timber, hitches are cut into the side walls of the shaft. Bearing sets are placed at regular intervals of 50 to as much as 200 ft.

In ground subjected to movement and swelling, jacket sets are placed to ease the operation of replacing broken timber. Jacket sets are expensive and it has been proved that by filling the space behind sets with sand installation of jacket sets becomes unnecessary.

Steel Sets

Steel sets have been proved to be of use in some districts. Steel set s last longer than timber sets, and eliminates the fire hazard. Steel sets can be of an advantage in solid ground which requires no lining or support. The steel sets are thus solely used to facilitate the placing of shaft guides, pipes, cables, and ladders. In extremely wet shafts or shafts that contain water of high acidity steel sets may fail from corrosion long before timber would decay. The cost of steel sets are higher than for timber, but shaft cross section can be kept smaller.

Steel sets are constructed of H beams or I beams and bolted or riveted together. Angles are used in the corners to make the set rigid. Corner angle-iron studdles correspond to the posts of a timbered shaft. Shape of steel sets is the same as timber sets, difference between the two being that one is constructed of steel and the other of timber.

As in the case of timber sets, steel sets must be kept a safe distance from the bottom of the shaft to prevent damage during blasting. Steel sets can be assembled on surface and lowered as a single unit or lowered in sections and bolted together in the shaft. A platform is used to work from, which also protects the sets from blasting. Blocking is done in the same way as in timbering by wooden blocks and wedges. As in the case with timber bearer sets must be used at regular intervals in order to prevent the sets from settling.

Over all steel sets make a nice job and increase in cost may be warranted by its greater life. Steel sets cost approximately a third higher than timber sets. Main objection to the use of steel sets is that in case of ground movement they can not be replaced by timber sets because of a lack of space.

Concrete Linings

The support of shaft walls with concrete is becoming more prominent the last few years. In the long run it proves to be the most satisfactory and cheapest. Not only does it provide a good support, but it is also fast to install. For ventilation it has the added advantage of providing a smooth lining, thereby keeping friction losses down to a minimum. Concrete also keeps the ingress of water down to a minimum. By keeping water out concrete prevents an increase in the humidity of air and also minimizes the cost of pumping.

The ge neral method of lining shafts with concrete is to use solid walls of concrete with dividers. Dividers may be of concrete, steel or timber. Certain walls of concrete between compartments impart added strength to rectangular shafts and permit thinner outside walls. Other methods of concrete support are the use of precast concrete sets as well as precast curbing.

Mixing of Concrete.

To obtain the best mix concrete, clean and chemically inert sand and gravel or crushed rock should be used. Water should be as pure as possible and free of harmful salts. Average size of aggregate used is 1-in. mesh. Strength of concrete mix depends on the local conditions and requirements. The best allround mix (the portion of cement to sand to crushed rock or gravel) for average work is 1:2:4. Where great strength is not required a mix of 1:3:6 may be used. If great strength in support is required steel reinforcement must be used with the concrete.

Since most shafts are sunk as fast as possible it is important to have a concrete that will set within a limited time. In South Africa they use monolithic concrete and add 1½ lb. of Calcium chloride per gallon of water in the mix. This mix will set within one hour after pouring.

Delivery of Concrete to Forms.

In most cases concrete is mixed on surface and delivered at forms by pipe line or buckets. In the case of buckets the concrete is lowered in bottom discharge buckets. The buckets discharge into launders from where it is distributed around the periphery of the shaft.

During the concreting of the Kelley shaft, Butte, Montana, the concrete was premixed and delivered at the collar of the shaft in trucks. The trucks discharged into a central bin from where the concrete was directed to the forms by pipe line.

Pipe lines are favored in the United States for the delivery of concrete at the forms. In South Africa they lower the concrete in Blaw-Knox concrete buckets whenever the Galloway stage is used. The bottom discharge buckets discharge into an "octopus". Blaw-Knox buckets have a capacity of 62.5 cu.ft. The "Octopus" is a receptacle of 22.5 cu.yard capacity, made of 3/16 inch mild steel plate. Ten 6-inch pipes are welded into the bottom to provide an outlet to the distributing hoses.

Fig. 15 shows the Galloway stage and its application to the lining of shafts. With the aid of the Galloway stage concreting and sinking can be done concurrently. Sinking and lining operations are done on a three-shift basis. Each shift completes the entire cycle. With the aid of the Galloway Stage and Octopus 22.5 cu. yards of concrete can be placed every 15 to 20 seconds. This is equivalent to 1½ to 2 ft. of lining every 15 to 20 seconds.

In order to prevent the segregation of concrete aggregate, and the consequent weakening of the structure, the concrete must be properly placed. One of the most common causes of segregation of aggregate is too much water in the original mix. The least amount of water should be used in order to provide a better grade mix. Sufficient water should be used to provide a plastic mix. Pozzoliths can be used with the mix to give a mix that will flow readily with the minimum amount of water. Pozzoliths thus serve as a wetting agent. Air vibrators are used to pack the concrete and to prevent the segregation of the aggregate. Vibrators also cause the concrete to flow in tight spots not necessarily reached by natural flow.

Forms.

Two types of forms are used -- built-in and removable. Modern method, however, is to use removable forms. It is cheaper since the same forms can be used over and over. The built-in forms are constructed out of lumber and built as the concrete progresses. Three or more sets of removable forms are required for concreting a shaft.

In concreting the Kelley shaft curtain walls were made of concrete. In order to provide openings in the curtain walls special steel forms were designed. These openings reduced the amount of concrete needed and also provides communication between compartments. The Kelley shaft was raised and timbered, concreting done after shaft was completed. As a result the timber sets provide an efficient skeleton form to construct the main forms of. Lagging was nailed to the outside of the wall plates to serve as a form. Each pour was carried up to a point 2 to 3 in. above the top of the wall plate above. Since this shaft was completed before concreting it was possible to start concreting at the bottom.

In designing steel forms it is important to design them in such a way that they may be removed with ease and reused. Most common practice is to make the forms in separate panels which can be bolted together with ease. Each section of the form can also be equipped with a small hinged door with beveled edges. When locked in closed position with steel pins to the adjoining section, these doors make a very rigid but yet easily removable form.

In South Africa it is the general practice to pour the concrete linings in 11 ft. rings separated by 18 in. gaps. Gaps are left to accomodate the permanent steel sets which is intended to be grouted into place after the sinking is completed. Steel forms used for supporting the concrete are suspended from the Galloway stage and rest on curb rings which become the bottom of the concrete shuttering. Steel forms are lowered into position by a hoist on the Galloway stage and pouring is done from the stage.

Advantages of using steel forms are as follows:

1. Greater precision can be obtained with less supervision.
2. Neater appearance of finished surface.
3. Only a limited number of forms are needed.
4. Can be installed at far greater speed.
5. Less leakage of water and cement and consequently a little stronger concrete.

Reinforcement.

Reinforcement in concrete walls tends to prevent the buckling of rectangular shaft walls, giving an added strength to the concrete. Concrete is weak in the presence of tensile strength and tensile fractures occur readily. When concrete is subjected to tensile stress it is advisable to use reinforcement. The reinforcement is usually placed on the inside of the concrete walls, where tensile stress is most likely to develope. Ordinarily reinforcing steel is 3/8 to 1½ in. in diameter. Spacing between bars varies from 6 in. to 1 ft. In cases where the ground is subjected to movement, reinforcing mats must be used. Reinforcing bars may be fabricated into mats, on surface or in place.

Curtain walls cast as an integral part of the lining impart an added strength to the concrete walls. Where this method is practiced less reinforcing is required. However, if ground is expected to move curtain walls are the first to fall. In this case curtain walls must be reinforced with I beams or rails. Old scrap iron and rails are also used in the ealls to give them added strength. About half of the metal-mine shafts are reinforced.

Guide attachments in concrete shafts.

Guides are a problem to attach in concrete shafts since it is difficult to place wooden blocks or sockets in the correct places to attach the guides to. Moreover, after the guides are installed they may not be in perfect alignment; causing an uneven guide surface. In order to avoid this, guides can be framed separately to fit the blocks or sockets. Adjustable sockets are also used and they seem to be most satisfactory. In the Kelley mine, steel sockets with horizontal slot were concreted into the walls. J-bolts were used to attach the guides to these sockets. Holes in the guides were drilled in the correct place to fit the J-bolts. Vertical alignment was attained by sliding the J-bolts in the horizontal slots of the sockets. This method of guide attachment has proved to be efficient and very satisfactory.

Conclusion.

With all the a dvantages of concrete, mentioned through-out this chapter it is easily seen why concreting has become in such great use. Not only does it serve the purpose required, but also furnishes a very neat piece of work. Concreting can also be done concurrently with sinking, such as in South Africa. As far as economy is concerned concreting compares very good with other methods of support.

Most concrete walls ~~are be~~tween 6 to 24 in., depending on the amount of support required. Concrete can also be kept at a relatively short distance from the bottom of the shaft.

Guniting.

Some ground being firm during sinking may after exposure to atmospheric air and water swell and flake off. It is therefore of importance to prevent swelling after exposure. Guniting the grund before this can happen often prevents swellimg. Guniting consists of spraying the walls with a liquid mixture of cement.

Further advantages of guniting are that it protects timber from fire; it also prevents the ingress of ground water in shafts, thereby increasing ventilation efficiency, and decreasing pumping cost. In order to prevent timber from decay behind guniting timber should be treated against decay.

PUMPING

Water at the bottom of a shaft retards sinking operations, there by making their handling important. Even small amounts can retard operations, as water makes the muck sticky and causes it to pack. Small amounts can usually be bailed out with bailers and bailing is cheaper than pumping. In cases where mechanical mucking machines are used, a certain amount of water is bailed out with the muck and hoisted in the buckets. Where great quantities of water are present pumps must be installed to handle the water.

In designing pumping facilities for sinking it is of importance to design them to handle any amount of water expected, efficiently. Not only should the pumps be able to handle the amount of water flow expected, but they should also be able to cope with any unexpected surge of water flow. Not more than one half of the rated capacity of the pump should be expected as a result of muddy water at the bottom of the shaft.

Different kinds of pumps can be used -- for short lifts the ordinary compressed-air pump may be used; and for long lifts it becomes necessary to use centrifugal pumps. All pumps must be serviced and inspected regularly. This is of importance since pumps in bad condition will not operate effectively and may be of no use in case an emergency arises. Spare pumps for replacement of broken down pumps must always be kept at hand; they also may pay off when a sudden surge of water flow is encountered.

Where long lifts are necessary and a large amount of water must be handled, sumps must be cut at stations for storage of discharge water. It is of importance to design sumps in such a way that they will be efficient and that they may be cleaned without tampering pumping. The sumps may be designed so that they will become permanent installations after sinking, or they may be only of temporary nature. Once sumps are completed and station pumps installed, air operated sump pumps may be used at bottom of shaft to pump water up to sumps.

Station pumps can be operated automatically and only require attendance for periodical check-ups. The station pumps can be of permanent nature to cut down later installation cost. Pump columns must be established in the shaft with future requirements in consideration. This will save time and money, since they will not have to be replaced later with the permanent columns.

The other method of handling water at bottom of shaft is by using air-driven sump pumps which discharge into the sinking buckets. The buckets full of water can then be hoisted and dumped on surface.

Water can also be handled with ordinary bailers. In sinking the No. 1 shaft at West Driefontein, South Africa, two 800-gallon bailers were always ready for immediate use in case of a sudden surge in water flow. The bailers had a net weight of 2,700 lbs. and can be filled in 6 seconds from the time dipping commences. Winder was capable to handle 10,400 gallons of water per hour when winding from a distance of 1,800 feet under single-drum conditions. The bailers discharged in the usual manner.

Water Rings.

Water running down a shaft can be discouraging to the workers and they should be directed to sumps by pipe line. This can be done by installing water rings in the shaft and transferring the water by pipe to the sumps, or the level below. If sufficient quantities of water are present it may be pumped directly from the water rings. Water rings are usually constructed of concrete to make it water-tight. In constructing water rings the shaft diameter or section is enlarged behind the timber or support to form a basis. These water rings are usually constructed below the water table. If the ingress of water is diffused over an entire length of shaft water rings must be installed at intervals.

VENTILATION

Ventilation in shaft-sinking operations is of importance for two reasons -- to provide fresh air for the men at the bottom of the shaft, and after the blast, the smoke and fumes must be removed before men can return to work. Since it is required to remove all fumes and smoke from the bottom of the shaft before sinking operations can be continued it is important to do this as fast and efficiently as possible. The longer it takes to remove the fumes, the longer is the delay in sinking operations. With increased depth it is imperative to keep the shaft as dry as possible and to have an effective ventilation system.

Ventilation in sinking shafts is either forced or exhaust. In some instances exhaust ventilation is used directly after the blast to get rid of the fumes and smoke; while forced ventilation is used during sinking operations. In most cases ventilation is afforded by a fan forcing the air through galvanized-iron or flexible tubing, which is carried down the shaft as it is sunk. By using an exhaust type of fan right after the blast fumes can be cleared faster. Re-entry time after the blast varies but should never be less than 30 minutes.

Size of the tubing varies according to the depth of shaft, the amount of fresh air required, and the size of the fan. Tubing of as low as 8 in. to as high as 36 in. in diameter has been used. Galvanized-iron tubing is more permanent and is less likely to fail. Ordinarily fan bag is easily torn by falling rocks and is hardly ever used in great lengths. It is sometimes used in extending the tubing for a limited length and time.

To improve the ventilation at the bottom of a shaft, tubing can be tapered at the end to increase the air velocity and cause a refreshing movement. Another innovation used in sinking the No. 5 shaft at Van Dyk, South Africa, is a 75-ft. length of sliding pipped riggid inside the 30-in. galvanized tubing at the bottom of the shaft. This 28-in. pipe is suspended on a 5/8-in. flexible galvanized-wire rope inside the ventilation column and lowered by a 50-h.p. Fulton hoist. This extension of the ventilation column is hoisted during blasting operations and lowered directly after the blast. Benefits derived from using this combination are as follows:

1. Blasting smoke is cleared within 10 to 15 minutes.

2. Dust during working cycle is kept to a minimum.

3. Fog from drilling machines is practically non-existent.

Ventilation was carried out with a 48-in. Brown fan capable of 30,000 c.f.m. against a water head of 17 in. At a depth of 3,800 ft. fan was exhausting approximately 13,000 c.f.m.

Ventilation is of great importance in shaft sinking. If fumes are allowed to cumulate at bottom of shaft it may prove to be fatal. Good air is always a morale builder in any working place.

SAFETY

Like in any other phase of mining, accidents in shaft do happen. However, the old saying is that accidents don't happen they are caused, holds true in this case too. Good planning and high morale in the working force goes a long way in preventing accidents. Bad planning in shaft sinking is one of the main reasons why addicents do happen in shaft-sinking operations. Very often accidents can be traced to defects in the equipment; this is inexcusable and should never happen.

Following are a number of causes of accidents in shaft sinking:

1. Bad planning.
2. Faulty equipment.
3. Objects falling down shaft.
4. Cumulation of gases at bottom of shaft.
5. Skip or cage.
6. Bad lighting.
7. Mucking machines.
8. Blasting
9. Ground water.

10. Bad morale.

All the causes mentioned above are actually a result of bad planning and supervision. Good planning and supervision can eliminate all these causes. Safety-fuse blasting should never be used in shafts. If something goes wrong with the hoist or skips after the round is spit it is just about impossible to prevent a bad accident. Electric blasting caps should always be used in shafts. As mentioned in the blasting chapter only one person should be in charge of the entire blasting operation. Before the round is wired, all lead wires should be checked to make certain that no current is flowing in the wires. The main switch on surface should always be kept locked and only the person in charge of the blast should have a key to this switch. The main switch should not be thrown until all persons are out of the shaft.

Accidents due to falling objects can also be eliminated by having safety doors at the bottom of the shaft and also on the surface. These doors should only be opened to allow the passage of the buckets or skips. One person at bottom of shaft should be in charge of the signals. If more than one person is allowed to operate these bells accidents can happen. A wrong signal can mean the loss of a person's life.

Where sinking and equipping is done concurrently, it is important to have a safety bulkhead or stage above the drillers' heads to stop any falling object. A sudden inrush of ground water has also been fatal in shaft sinking. If any water fissures are expected pilot holes should be drilled during each round to test ahead of the blast.

Where mucking machines are used the operator should be protected with a bulkhead from falling objects. This can easily be done where a sinking stage is used. Doors can be installed to allow for the passage of the buckets or skips. Persons below the mucking machine should also watch out for rocks in the machines claws, which may prevent the jaws to close and thereby allowing finer material to run out.

In order to prevent a sinking bucket to move from side to side during hoisting, it can be hoisted in a skeleton cage with guide shoes.

Flood lights are becoming prominent in sinking shafts. They have the advantage of providing better illumination at all spots at the bottom of the shaft. The only time flood lights cannot be used is during the time the round is loaded and wired.

The accumulation of gases in shafts should never be allowed. Ventilation should be sufficient to prevent the accumulation of gases. Men should never be allowed to enter a shaft until all gases are removed and a sufficient blowing over time has passed. In one shaft in Africa methane gasses were allowed to accumulate and an explosion resulted in the death of a number of men.

SINKING RATE

The sinking rate of a shaft depends on various factors -- on the size of the shaft, number of men employed, number of shifts worked per day, ground conditions, type of shaft, location of shaft, and the planning and organization of the operation. Sinking conditions are probably the main factor in sinking rates. In extreme cases as little as 1 ft. per day has been obtained compared to as much as 25.3 ft. per day. Table No. 1 gives a list of the world's sinking records for one month's time, established during the past 25 years. The latest world record of 763 ft. in 30 days is remarkable and an example of good planning and organization, In establishing this record at the Monarch shaft of the West Rand Consolidated Mines, Ltd., Krugersdorp, South Africa, a total of 220 men were employed per day on a 6-hr. 5 shift basis. Sinking and equipping was done concurrently.

Although the total footage per day sunk varies in shafts over the world it is of importance to note that the feet advance per 8-hr. man shift stays within close range. Table No. 2 is a list of the feet advance per 8-hr. man shift, for a number of shafts. It appears to me that the average sinking rate per 8-hr. man shift is in the neighborhood of .25 ft.

Table No. 2

Sinking Rate Per 8-hr. Man Shift

Shaft	Location	Rate in Feet
San Maneal		.222
Water Lily	Utah,	.382
Kelley	Butte, Montana	.25
Mountain Con	Butte, Montana	.30
Hope	Clark Fork, Idaho	.1001
Monarch	South Africa	.136
Van Dyk	South Africa	.216
Atlas	Mullan, Idaho	.542

It might be mentioned that these figures are an average and they vary from day to day. In sinking the Kelley shaft the rate per 8-hr. man shift varied from .2 ft. to .374 ft. The table should not be used as a comparison since conditions varied immensely; it should be of importance only as to what advance per man shift to expect. From the table it appears that a sinking rate of .3 ft. per 8-hr. man shift is about the highest to expect from any sinking operation. Mechanical mucking should be able to increase this rate, but until mechanical mucking improves the best anybody could hope for is .3 ft. per 8-hr. man shift. In sinking the Monarch shaft a total of 26 muckers were required for each 6-hr. shift. Mechanical mucking could have decreased this figure to about 20, giving a rate of better than .2 ft.per 8-hr. man shift.

COST

The cost of a shaft depends on the size, depth, sinking equipment, planning and organization, ground conditions, and sinking rate. It has been proved that the higher the sinking rate the less is the cost per foot. At the No. 5 shaft of Van Dyk, South Africa, an advance of 45 ft. in one month cost them £ 254.6 per ft. compared with a cost of £ 54.93 per ft. for 302 ft. of advance in one month. Average cost per ft. advance was £ 86.20.

Cost per ft. advance is greatly effected with the mucking operation. Mucking cost per ft. advance is usually the greatest in sinking a shaft. The high cost of mucking makes it the one phase in sinking operations that is always drawing attention and where the most improvement has been made during the past years. As mucking efficiency increases the cost per foot decreases.

Cost of supporting the shaft walls is also high and it is important to design the support so that it is effective yet not too expensive. With new methods in concreting shafts, concreting has become the most desirable support. Cost of concreting a shaft has in the last few years decreased and it now compares favorable with other types of support.

Table No. 3 gives the detailed cost of sinking the Hope shaft, Idaho.

Table No. 3 -- Direct Shaft-Sinking Costs, Dollars per Foot Sunk.

	Labor	Repairs	Power	Explos-ives.	Timber	Total
Drilling and Blasting	8.297	1.164		6.463		15.924
Timbering	12,391	.800			10.39	23.581
Mucking	20,743	.166				20.909
Hoisting	12.229	.133				12.362
Pumping	-	2.083		.439		2.576
Ventilation	-	.120				.120
Rock Disposal	13.559	-				13.559
Supervision	14.127	-				14.127
Administration	9.197	-				9.197
Blacksmithing	8.034	-				8.034
Miscellaneous	4.149	.461	8.055			16.650
Total---	102.726	4.927	8.055	6.956	10.39	137.039

From Table 3 we see thus that the cost for labor is by far the most expensive item in sinking a shaft. Even a small increase in the advance per man shift will reduce the cost per foot to a great deal.

Depth of shaft also increases the cost per foot, since heavier equipment is needed and hoisting time increases. Size of the shaft usually increases the cost but not in direct proportions. The only phase where the cost increases in direct proportions is hoisting. However, nothing increases the cost of sinking a shaft as much as delays. Just a small delay may mean the loss of a round, which in turn decreases the rate per 8-hr. man shift. Delays are often due to bad planning and organization. In sinking shafts in South Africa, where the Galloway stage is used, one misplaced hole can cause the stage to get stuck, thereby hampering the entire operation. By careful direction of effort, much time can be saved in shaft sinking and cost per foot reduced, and thus the overall cost of the shaft. This means a reduction in the initial cost during the unproductive stage of the mine.

Table No. 4 lists the cost of sinking shafts per foot over the world.

Table No. 4 - Cost per ft. of sinking shafts.

Shaft	Location	$/ft.
Water Lily	Utah	57.710 (pre war)
Hope	Clark Fork, Idaho	137.039
Iron King No.7	Hambolt, Arizona	156.330
Van Dyk, No. 5	South Africa	239.000
Blyvooruitzitch	South Africa	
rectangular	"	306.000
"	"	289.000
circular	"	242.000
St. Helena, No.3	South Africa	162.800
Atlas	Mullan, Idaho	181.000

CONCLUSION

The present tendency is to sink shafts with large cross section to provide large compartments for cages on which loaded trucks with timber and other underground supplies can be run. Circular shafts are becoming prominent in South Africa for ventilation purposes, and where hydrostatic pressure is to be withstood. In Butte, where ventilation shafts used to be octagonal, they now use rectangular shafts instead.

With the development of new techniques in concreting shafts, concreting now competes favorably with other methods of support. Most shafts in South Africa are concrete lined, concreting done concurrently with sinking operations.

Mucking is now done with mucking machines at most places. The only place where hand mucking is still used to a certain extent is in Africa, where cheap labor is still available. Although mucking machines are not as efficient as could be wished for, they are of great value in shaft sinking and cut cost considerably. With new developments mucking machines should be able to decrease the cost, and increase the speed of sinking to a great extent.

Specialists are required for all shaft-sinking operations to obtain a high sinking rate and a low cost. With increased costs it now has become necessary to sink a shaft as fast as possible. Proper planning and organization is of the greatest importance in sinking a shaft efficiently. Sinking rates vary from less than 1 foot a day to 25.3 feet a day, average advance per 8-hr. man shift is less than .3 ft. The cost depends on the size of the shaft, the equipment used, conditions, and the organization. The cost of most shafts is between 100 and 200 dollars per foot advance.

Sinking operations usually extend over 24 hours per day. Three shifts are the most common used, however, in establishing the world record of 763 feet in one month at the Monarch shaft, Krugersdorp, South Africa, four six hour shifts were used, each shift completing the entire cycle. Best sinking rate can be obtained if each shift completes the entire cycle instead of only doing the work at hand. In order to complete an entire cycle, planning must be correct and no delays can be allowed.

In conclusion, I would like to say that no attempt was made in the report to cover every detail of shaft sinking. The report as it is, is only meant to give the reader a general idea on shaft sinking. Shafts sunk in bad ground are not discussed, since I felt that it is beyond the scope of this report. In order to guide the inquisitive to additional data a bibliography can be found at the end of this report.

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